

Running Developments Concerning Aluminium Fuel Tanks for Passenger Cars

A. Smeyers and JP. Baekelandt

CORUS Aluminium Rolled Products, Duffel, Belgium

J. van Rijkom, R. van de Moesdijk and H. Werk

CORUS Research, Development & Technology, IJmuiden, The Netherlands

D. Schildermans and L. Janssen

INALFA Metal Products, Hamont-Achel, Belgium

Copyright © 2003 CORUS Aluminium Rolled Products

ABSTRACT

Complex shapes with integrated functions become more and more a well-known feature in the automotive world because of cost-savings, car comfort and safety regulations. As a consequence, the demand for higher formability is becoming an important key issue for the car manufacturer and its suppliers. Compared to classic steel grades, aluminium has a disadvantage with respect to formability at room temperature. However, increase of the forming temperature up to 350°C (below super-plastic temperatures) can be an attractive way to improve the formability at reasonable costs which results in an increased design freedom which is obligatory for some applications (like for instance fuel tanks for passenger cars).

This paper highlights the results of a study concerning

- Warm forming properties of commercial available aluminium alloys of type AA5018 (3.5wt%Mg) and AA5182 (5wt%Mg).

A number of independent institutes executed several bulge- and tensile tests at different strain rates and elevated temperatures (< 350°C). The tensile test results at elevated temperatures of the different institutes were evaluated in order to establish an accurate, reliable and reproducible test method and to find out which parameters can influence the warm formability of aluminium in a positive way.

- The most appropriate production technique to perform warm forming of aluminium.
- The development of new robust and fast welding techniques to achieve an emission free joint between both shells of an aluminium fuel tank.
- The fuel and atmospheric corrosion behaviour of uncoated aluminium alloys.

INTRODUCTION

Aluminium alloys have already proven their lifetime durability in truck fuel tank applications in the past. In addition, the manufacturability and weldability are outstanding, especially for the AlMg2.5 (AA5052) & AlMg3.0 (AA5754) alloys. Corus Aluminium Rolled Products (CARP) Duffel is a long-term supplier of aluminium sheet and coil for the production of LKW (truck) fuel tanks (see figure 1). These aluminium truck fuel tanks are typically made out of 2 to 2.5 mm thick sheet and experience has proven for this application that the used aluminium alloys have, without additional coatings, an excellent atmospheric- and fuel corrosion behaviour (see figure 2).

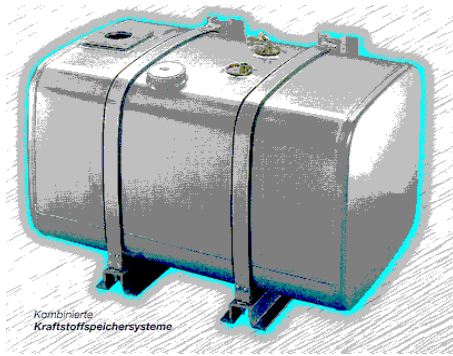


Fig. 1 Truck fuel tank for diesel applications



Fig. 2 Corrosion free inside of a 7 year old aluminium truck fuel tank

Compared to truck fuel tanks, fuel tanks for passenger cars have a design with a considerable higher complexity. In order to create the possibility to produce such complex fuel tanks in high volumes out of aluminium sheet, new forming techniques like warm hydroforming or warm deep drawing and new joining techniques are required. Additionally, extensive corrosion tests in new fuel systems and atmospheric conditions need to be executed. After all, the corrosion behaviour of a truck fuel tank with a wall thickness of at least 2 mm is less critical as the corrosion behaviour of a fuel tank for passenger cars with a typical wall thickness of 1.0 to 1.2 mm.

Fuel tanks for passenger cars are traditionally made out of steel grades coated with lead-tin alloys (tern plate) or out of high-density polyethylene (HDPE). However, both materials are experiencing problems to comply with recent environmental regulations.

After all, the use of steel grades with a coating containing lead is prohibited from 1 July 2003 onwards due to article 4 of directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 which states that Member States shall ensure that materials and components of vehicles put on the market after 1 July 2003 do not contain lead, mercury, cadmium or hexavalent chromium other than in cases listed in Annex II under the conditions specified therein. On the other hand, the industry producing HDPE-tanks still doesn't seem to be able to meet future permeation standards. Despite of the fact that this industry switched from the monolayer-HDPE tank technology to the multilayer tank technology or even more complex solutions, many signals coming out of the market indicate that the current state of this technology isn't able to achieve the prescribed stringent emission rate of hydrocarbons. As a consequence, implications for this industry are the need to switch to even more harder-to-recycle material systems and even more expensive processes to produce these fuel tanks.

The drive and legislative requirements to reduce the fuel emissions for passenger cars are originated by CARB (Californian Air Resource Board). The CARB - LEV II requirements restrict from 2004 onwards the allowable evaporative hydrocarbon (HC) emission level of a parked vehicle to 0.5 g a day and are among the most stringent set of regulations in the world.

To help guide its research and development programs, the automotive industry allocated less than 200 milligrams a day of that emissions allowance to fuel systems and approx. 300 milligrams a day to the rest of the car (for emissions originating from tires, fascias, headliners, etc...). Considering emissions caused by components of the fuel system as for instance fuel lines, connections, etc ... evaporative HC emissions of much less than 150 milligrams a day are allocated to the fuel tank itself. Different figures can be found about the allowed emissions allocated to the fuel tank itself but figures of max. 50 milligrams or even much less are mentioned frequently. Additionally, the systems will have to meet a 15-year/150.000 miles durability requirement for 2004's CARB Level II [Ref. 1 to 6].

IMPROVED MATERIALS POTENTIALS

Common knowledge is that an alloy with a good warm forming behaviour is characterised by a good necking resistance at relatively high strain rates. At room temperature, alloys with a high work hardening effect have good necking resistance.

At elevated temperatures ($> 150^{\circ}\text{C}$), this strain hardening effect disappears. At these temperatures and in the case of aluminium, a good necking resistance is achieved by means of a high strain hardening effect. Many efforts are currently dedicated to research for parameters which have a positive effect on this strain hardening effect.

A lot of literature is already available concerning the improved ductility of aluminium alloys at temperatures of 150 to 350°C . The formability of many (non heat treatable) aluminium alloys at these temperatures is equal to or even superior to the formability at room temperature of the most frequently used steel grades (see figure 3).

An additional advantage of the processing of Al-Mg alloys at higher ($>100^{\circ}\text{C}$) temperatures is the absence of serrated yielding which is a typical phenomenon when these alloys are formed at ambient temperature.

Applying temperatures up to "only" 350°C (below superplastic temperatures) has the advantage that applicable strain rates (read forming speeds) remain relative high, grain sizes of non-heat treatable alloys remain unchanged and no aluminium grades with exotic alloying elements are necessary.

In spite of the fact that the grain size isn't influenced at these temperatures, this doesn't want to say that the (intergranular) corrosion behaviour stays unchanged (compared to a cold formed part). Amongst others pitting corrosion tests are running to determine the influence of the warm forming process on the corrosion behaviour of the end product.

NEW AND INNOVATIVE FORMING PROCESSES

Deep drawing at ambient temperature is a technique that does not exploit fully all the material's forming potential. Cold hydroforming, whether or not followed by a deep drawing step, warm hydroforming, high velocity (explosion and electromagnetic) forming, superplastic forming and warm deep drawing do exploit the forming potential significantly more. However, in the case of warm sheet hydroforming, the industry isn't (yet) ready to upgrade this technique from its laboratory phase to an industrial production phase. Main reasons are assumed to be the high investment cost (for tooling and press), the low production speed and the fact that even cold hydroforming of sheet is a very young production technique and needs maturing first.

In the case of tube hydroforming at higher temperatures, more interest of the industry is noticeable.

Due to the fact that;

- cold deep drawing is a wide spread and well known forming technique,
- warm deep drawing is already being used for steel grades and
- low takt times are achievable,

warm deep drawing received more interest from the industry as a potential industrial production technique.

After having explored and demonstrated the possibilities of warm hydroforming extensively in the framework of a EUREKA project, Corus Aluminium started, in cooperation with a press shop (Inalfa), a research programme subsidised by the Flemish government (IWT) to determine the process parameters (lubrication, temperatures, etc...), process window, achievable takt times, tool design, achievable degree of deformation, associated costs, etc... of warm deep drawing.

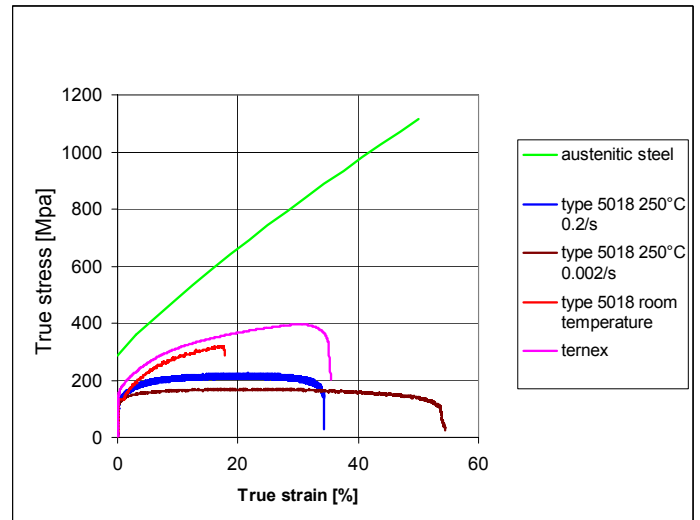


Fig. 3 Comparison of achievable true strains

WARM FORMING PROPERTIES

In general, one can state that the achievable degree of deformation of AlMg alloys at ambient temperature increases with the amount of Mg.

However, warm bulge tests pointed out that at temperatures higher than 200°C, higher bulge heights could be achieved with the 3.5wt%Mg alloy (type AA5018) compared to the ones that could be achieved with the 5wt%Mg alloy.

In order to be able to advise customers which alloy is optimal to use in case of warm forming, Corus Aluminium investigates parameters that have a positive effect on the achievable degree of deformation at higher temperatures.

This paper highlights the first findings resulting from the running and finalised research programmes.

To investigate the forming properties of some 5xxx alloys, elevated temperature tension tests (uniaxial) following the ASTM E21 - 92 specification were executed in combination with warm bulge tests (biaxial).

ELEVATED TEMPERATURE TENSION TESTS

Seven different institutes were contacted to perform warm tensile tests according to ASTM E21 – 92 or DIN EN 10 002 Teil 5, which finally resulted in the execution of warm tensile tests on 5xxx and / or 6xxx alloys by 4 different institutes. It became clear that only one of these laboratories could perform reliable warm tensile tests with a constant strain rate up to 300°C, although also here the reproducibility is subject to some optimisations.

Other laboratories couldn't execute the tests at constant strain rate, had problems with the clamping of the specimen, had limited and / or not uniform heating possibilities, had to use dimensions of specimen which don't give correct results, etc...

Final warm tensile tests were executed according to ASTM E21 - 92 (Re-approved 1998) on the commercial available aluminium alloys type AA5018 (3.5wt%Mg) and AA5182 (5wt%Mg).

At this institute the specimen were tested using an Instron 8500 servo-hydraulic test stand and an automated computer controlled testing procedure. Each specimen was heated up to the test temperature (between 150 and 300°C) and soaked for 30 minutes prior to testing. During testing, the temperature was within + and -5 degrees of the targeted test temperature. The specimens were then tested in strain control (0.2 /s and 0.002/s) using a 1.00-inch gauge length extensometer. Data for load, stroke and strain were collected throughout the test. After testing the 0.02% yield strength, ultimate strength and plastic elongation were determined. The data between the proportional limit and the ultimate strength were used to determine the n and k values for the test.

The flat specimen with a width (W) of 0.25 inches and a reduced gauge length (G) of 1.250 inches were machined according to ASTM E8 – 00b. The thickness of the specimens was the full thickness of the received material (between 1.0 and 1.5 mm).

DIFFERENCES IN ALLOY BEHAVIOUR

The warm forming behaviour of four alloys (5754, type 5018, 5182 and 6016) was investigated. However, most research was focussed on the alloys type AA5018 (3.5wt%Mg) and AA5182 (5wt%Mg). As mentioned earlier, results of tensile tests on room temperature on alloy 5182 show a higher elongation as for alloy type 5018 (see table 1).

Table 1: Room temperature properties of investigated 5xxx CARP alloys

No	Alloy + Temper	Rm (Mpa)			Rp0.2 (Mpa)			A80 (%)		Au (%)		n (10-16%)	r (mean)
		min	max	typical	min	max	typical	min	typical	min	typical	typical	typical
No1	CARP832 -O/H111 5754	190	230	215	85	135	110	19	23	17	20	0.25	0.7
No2	CARP839 -O/H111 type 5018	210	250	235	115	150	125	19	23	16	20	0.26	0.7
No3	CARP849 -O/H111 5182	255	295	275	110	160	135	22	28	19	24	0.30	0.65

The high Mg 5182 alloy has a typical A80 elongation of 28%, which is significant higher as the elongation of the lower Mg type 5018 alloy.

However, the executed warm tensile tests on both alloys make clear that at elevated temperatures and low strain rates, alloy type 5018 reaches higher elongations as alloy 5182 (see figure 4). This phenomenon was confirmed by the warm bulge tests executed with two different flow rates by the Dutch institute TNO by order of Corus Aluminium (see figure 5 and 6).

The in figure 5 mentioned figures are mean values of 3 tests. These results indicate that alloy type 5018 has higher bulge heights at temperatures > 150°C independent of the flow rate (strain rate).

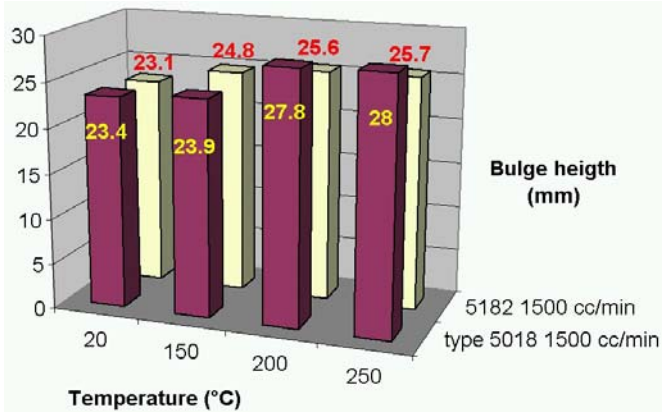
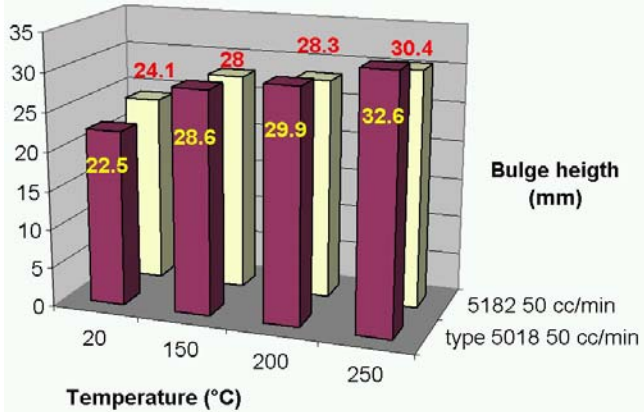


Fig. 5 Achieved bulge heights as function of alloy, temperature and flow rate (strain rate)

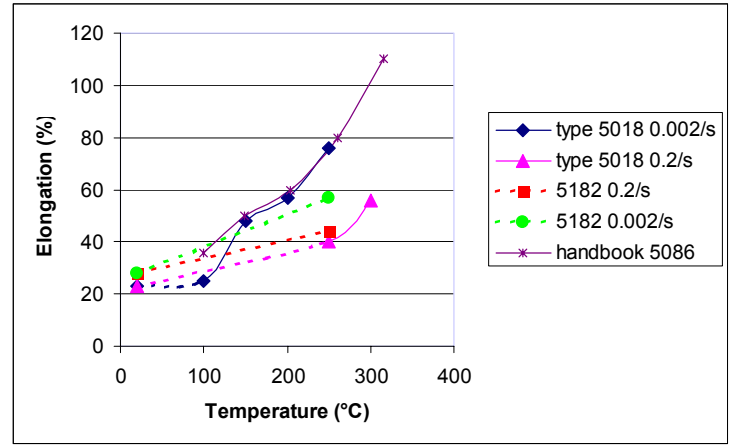


Fig. 4 Elongation of alloy type 5018 and 5182 at elevated temperatures

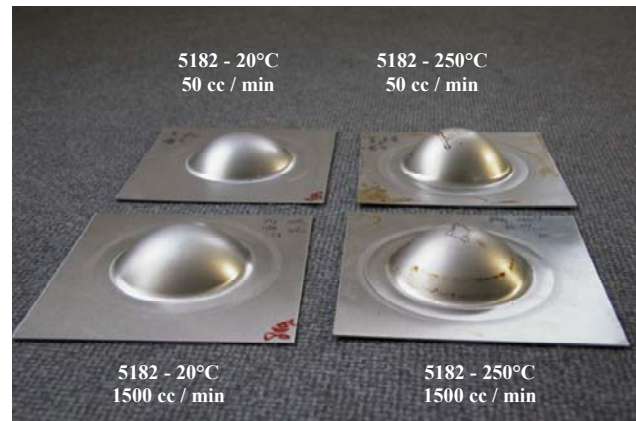


Fig. 6 Results of bulge tests on alloy 5182 at elevated temperatures

50 cc/min equals a strain rate of 0.0065/s (on bulge top at 20 mm height)
 1500 cc/min equals a strain rate of 0.2000/s (on bulge top at 20 mm height)

A strain rate of 0.2/s is a realistic mean strain rate that occurs during commercial deep drawing processes at room temperature

The results of the tensile tests shown in figure 4 don't confirm this. Out of this figure, one could conclude that at higher strain rates (0.2/s), both alloys achieve the same level of elongation. Due to the low amount of warm tensile tests executed with a strain rate of 0.2/s, more confidence is put in the results of the bulge tests. Additional warm tensile tests will be executed to be able to draw final conclusions. On the other hand, one still needs to keep in mind that there always can be a difference in uniaxial en biaxial forming behaviour of alloys.

In order to find out the metallurgical reasons for this difference in forming behaviour, additional warm tensile tests on aluminium grades with different thermo mechanical processing and / or of a different composition are currently being executed. Conclusions should lead to the development of a grade with excellent warm forming behaviour.

Note that in case of a flow rate of 50 cc/min (see figure 5) the achievable bulge height for type 5018 alloy raises from 22.5 mm at RT to 32.6 mm at 250°C, which is a tremendous improvement of 45 %.

Note also that at a temperature of 100°C there isn't yet an improvement of the elongation. Positive effects of the temperature on the formability start only at a temperature somewhere between 100 and 150°C, depending of the alloy and thickness of the sheet.

STRAIN RATE SENSITIVITY

As already extensively published, the formability at elevated temperatures decreases when the forming speed / strain rate increases (as can be seen in figure 5 and 7).

This phenomenon could make warm forming of aluminium less profitable. The university of Paderborn proved in the framework of the project "Warmhydromec" that this problem can be overcome (in the case of hydroforming) by the combination of different forming speeds. Started with a higher forming speed to produce the rough form after which was switched to the low forming speed to achieve the high degree of deformation and to produce accurately all fine details present in the die (see figure 8).

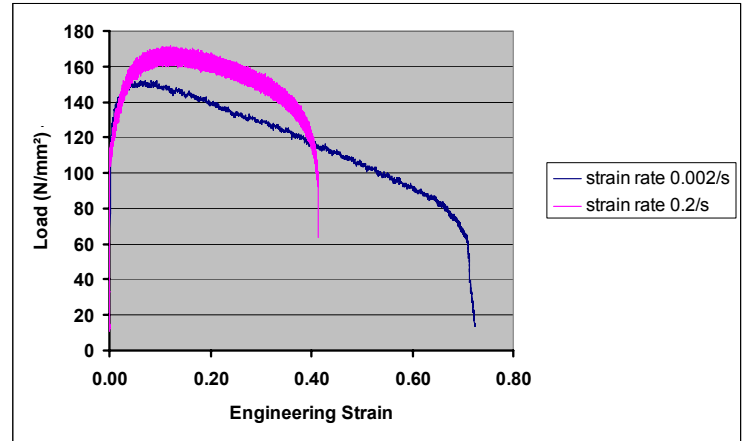


Fig. 7 Strain rate dependence of alloy type 5018 at 250°C

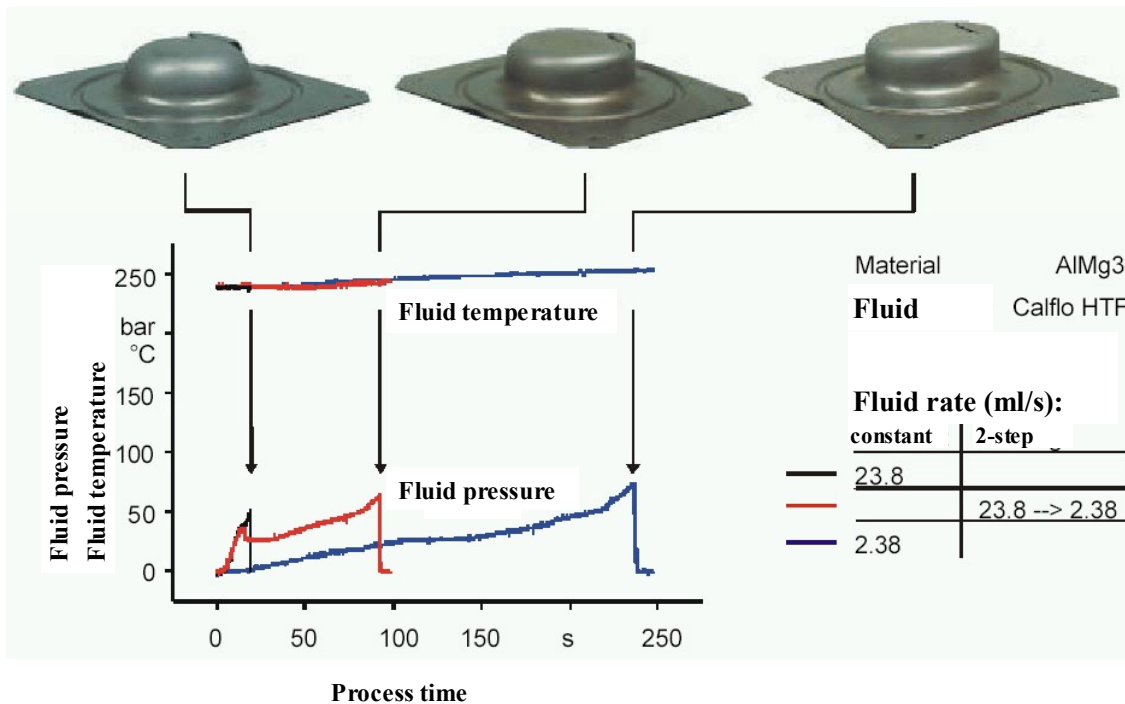


Fig. 8 Influence of forming speed and combination of forming speeds on achievable degree of deformation

WARM DEEP DRAWING TRIALS

Extensive trials executed in cooperation with Inalfa at Inalfa's facilities at Hamont-Achel resulted currently already in a square cup with a Limiting Draw Ratio (LDR) of 2,9 at a temperature of approx. 300°C (see figure 9).

It should be emphasised that the die radius was deliberately chosen to be only 5 mm, the press speed was as high as 10 mm/s and the aluminium blank with a thickness of 1,2 mm wasn't preheated. Also important to know is that the used press, due to the limited dimensions of its frame (read press opening), didn't allow a larger cup height than the achieved 220 mm.

Last but not least, one also needs to know that the following unfavourable phenomenon occurred while deep drawing until a depth of 220 mm.

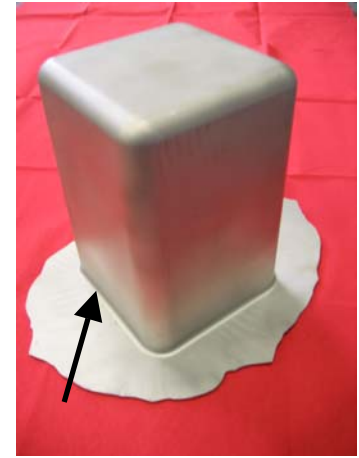
With the chosen tooling and press, a drawing depth of approximately 180 mm could be achieved in 1 step. To achieve a total drawing depth of 220 mm, it was necessary, after achieving a drawing depth of approx. 180 mm, to remove some supporting parts of the blank holder tooling. As a consequence, it was necessary to open the press again partly after achieving this 180 mm for 5 up to 10 seconds before the final drawing depth could be achieved.

Cups with a LDR of 2,54 were produced in one step with a speed of 30 mm/s, which is the maximum speed of the used press.

A good tribological system is achieved but still needs to be optimised. Currently, an innovative new tool coating is used in combination with a high temperature resistant lubricant, which assures a more uniform distribution than lubricants based on boron nitride.

As can be seen on the picture, the applied blank holder force resulted in an almost wrinkling free flange.

The heating system, which is incorporated in the tooling, doesn't require an exotic design of the tooling, doesn't require the purchase of exotic components, allows easy maintenance and has a high energetic efficiency.



FINITE ELEMENT MODELLING

Most commercial available finite element simulation models are excellent to perform calculations about deep drawing of steel sheet at ambient temperatures. These models are however not suitable to perform calculations when aluminium sheets are used and when forming is executed at elevated temperatures because of following 2 reasons. First of all, most commercial available FE models use steel material models to perform their calculations. Even at ambient temperature, these steel material models generate incorrect information about the formability behaviour of aluminium in case of biaxial load (see the difference in calculated yield locus between the Hill model (for steel) and the Vegter model (Corus model for aluminium) shown in fig. 10).

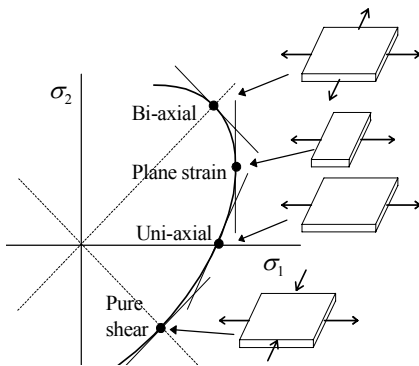


Fig. 11 Vegter description of yield locus

Secondly, at elevated temperatures, both the strain rate and temperature have an enormous influence on stress strain relations (work hardening effect). Current models aren't capable of describing this complex relationship accurately by means of one set of parameters.

Therefore, a continuum like model, in which dislocation movements and dislocations densities are incorporated, has been created on a physical basis at the TU Twente in cooperation with and by order of Corus. This model has already been validated by means of the production of very small cups at different elevated temperatures. The validation by means of larger and in an industrial environment produced prototypes will be executed in the framework of the running IWT research programme.

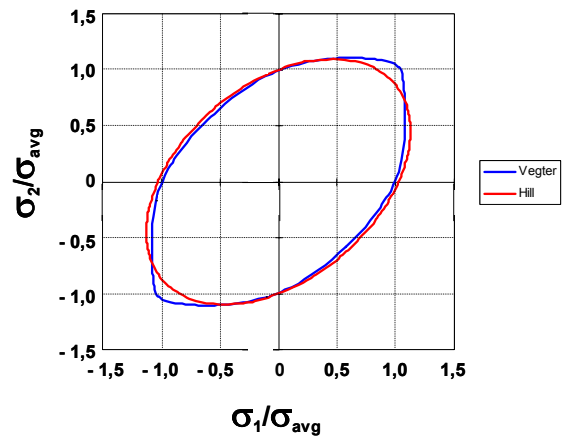


Fig. 10 Difference in calculated yield locus between Vegter and Hill models for alloy 5182

JOINING TECHNOLOGY

In general, one can definitely state that welding aluminium is more difficult than welding steel. Nevertheless, experienced and well-trained workers have no problems with producing reliable gastight joints in aluminium by means of MIG and TIG welding as now is being done already for more than 10 years for the production of truck fuel tanks and truck pressure vessels. However, achievable speeds of these welding processes are much too low to be appropriate for the cost effective production of fuel tanks if one needs to produce larger quantities (as for instance 1200 pieces) each day. Taking these large quantities and the fact that a fuel tank is a safety part into account, one should definitely apply a welding technique that assures a reliable weld seam quality that can be produced by manner of speaking with closed eyes but that can be checked automatically. In case of welding steel fuel tanks, this is achieved by means of applying the roller seam welding process. No real measuring techniques are available to control the internal quality of the weld seam of a fuel tank. However, measuring systems that inspect the surface quality of the weld seam are nowadays able to reject with a high reliability weld seams with internal failures thanks to the link between many years of failure analysis's and measuring results of the surface aspect of roller seam welds.

Such an experience is not available for other welding processes such as amongst others laser welding. As a consequence, it's harder to introduce such processes as a solution for joining 2 shells of a fuel tank for passenger cars.

Compared to steel, aluminium has also the disadvantage that up until now it's never used for the production of large series of fuel tanks for passenger cars. Only very few models of small volume luxury cars are already or are foreseen to be equipped with an aluminium fuel tank. Welding speed is for such low volume productions not a critical issue. As a consequence, TIG, MIG and other low speed welding processes are without question suitable.

In the mean time, a cooperation with an automobile manufacturer was founded to find a suitable welding technique to produce larger quantities of an aluminium fuel tank for passenger cars and to find out whether the corrosion resistance of (blank) aluminium is sufficient to guarantee the requested 15 (or even 20) year durability.

BRAZING SOLUTION

Much energy was in first instance put into a brazing technique. An aluminium foil with a Ni-based coating (foil a) on both sides was put in between the flanges and heated up by means of a Controlled Atmosphere Brazing (CAB) furnace. The specific composition of the coating on top of the aluminium foil results in a rather drastically reduced melting temperature (between 490 and 550°C) of the foil and surrounding skin of the base metal of the flanges. As a consequence, very wide joints (approx. 10 mm) with a high quality are achieved while the major part of the base material of the flanges isn't melted (see figure 12).

However, due to the fact that no reliable heating technique could be found to heat up locally the foil in between the flanges to a temperature in between a narrow temperature range, this research path was abandoned. Trials pointed also out that roller seam welding of this concept didn't generate a good joint. On the other hand, a similar concept with another special foil (foil b) in between both flanges gave excellent roller seam welding parameters and a good joint quality. Research within Corus Aluminium N.V. was finally focussed on roller seam welding of this concept (foil b), another concept and laser welding.

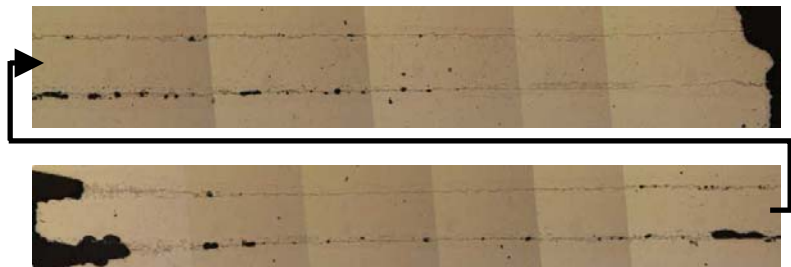


Fig. 12 Achieved joint by means of a foil with a Ni-based coating

ROLLER SEAM WELDING WITH A FOIL

Joining of aluminium with classic roller seam welding is known to be problematic in general. The natural oxide film of a few nanometres on the aluminium surface has a high and quite variable electrical resistance and a high melting point. Aluminium causes also much electrode pickup. This pickup changes the weld conditions and results in an inconsistent and improper weld quality.

In case of roller seam welding of the concept with the special foil (foil b) in between both flanges, the power needed for establishing a weld is reduced while a very good weld quality is achieved (see figure 13). As a consequence, the lifetime of the electrodes is improved. Another advantage of this concept is the generated wide process window for welding 5000 and 6000 series aluminium alloys. Alloy type AA5018 (3.5wt%Mg) can for instance be welded with a secondary weld current in between 10,8 and 13,1 kA and alloy 6016 can be welded with a secondary weld

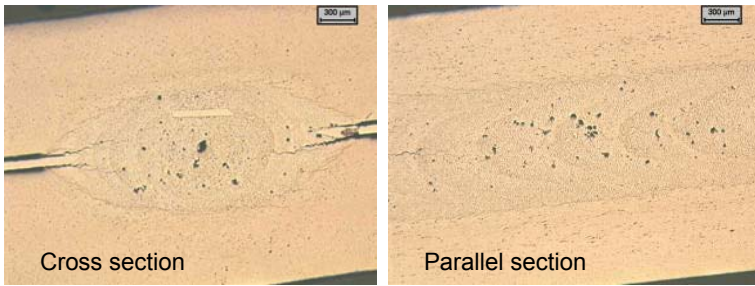


Fig. 13 Cross- & parallel section of achieved weld quality by means of the foil b concept

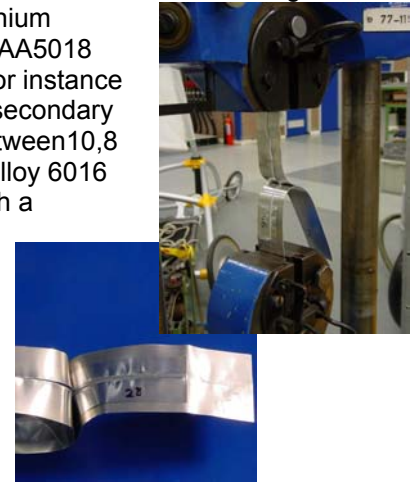
current in between 11,2 and 13,05 kA.

Trials were executed with a 50 Hz AC power source. The use of medium-frequency transformers will definitely give an even larger process window. Almost all trials were executed with a welding speed of 5 m/min.

The strength of the weld was tested by means of tearing both flanges apart with a tensile testing machine. The strength of the joint was judged to be good when the full weld seam was pulled out (see figure 14), which means that the strength of the weld seam is higher than the strength of the base material.

The fact that the foil needs to be guided in between the flanges doesn't simplify this welding process but is a problem that can be overcome. Big problem remains the start = end point of the weld where an overlap of the foil causes welding problems.

Currently, a solution is worked out that applies the same joining principle and that results in the same welding parameters and weld seam quality but doesn't require the feeding in of a foil.



ROLLER SEAM WELDING WITHOUT A FOIL

Another roller seam welding technique that is based on a completely different principle as mentioned above is also found and looks up until now as the most promising one. This principle makes it able to weld aluminium sheets without any surface preparation, coating, foil in between the flanges, etc... and allows achieving high welding speeds. Trials executed on two sheets of alloy 5052 with a thickness of 1 mm made clear that achieving a welding speed of 3,5 m/min is no

problem at all. It became also clear that achieved seam widths increased with applied current level (see figure 15). Within a secondary weld current range of 1,5 kA good weld seam qualities were achieved. However, the amount of pores present in the weld seam isn't the same for each weld seam width. All welds are good but some optimisation still needs to take place to achieve in all cases the best possible weld seam quality. This optimisation will partly be done by the R&D

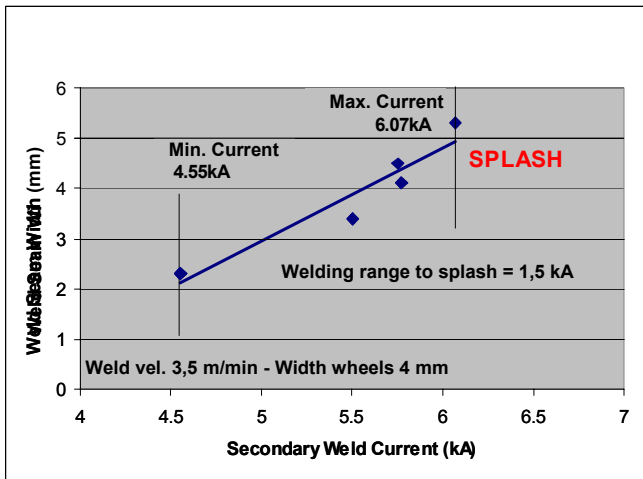


Fig. 15 Weld seam width in function of weld current

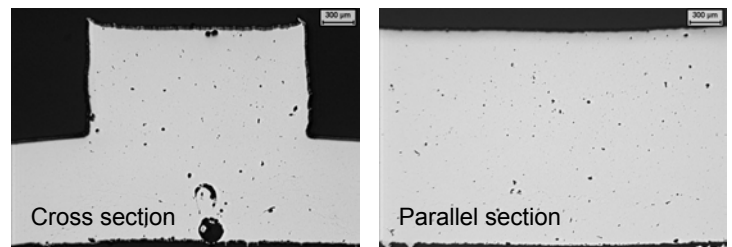


Fig. 16 Achieved weld seam quality

department of Corus. Trying out and optimisation of this welding technique on an industrial welding line will be done together with a leading supplier of roller seam welding equipment and in cooperation with the automobile manufacturer. Figure 16 gives an idea of the achieved weld seam quality at a welding speed of 3,5 m/min and a seam width of 3 mm (→ weld current of approx. 5,15 kA). This figure is taken after determining the strength of the joint. In other words, after tearing off the top base material.

LASER WELDING

Corus Aluminium N.V. and Corus RD&T have a lot of experience and knowledge concerning laser welding of aluminium. Many years of research and deliveries of prototypes have made that Corus Aluminium N.V. is the first supplier of serial deliveries of Aluminium Tailor Welded Blanks for the luxury car Lamborghini Gallardo. With the same laser equipment used for the production of these TWB's different laser welding concepts were tried out to find a solution for joining two shells of an aluminium fuel tank. Only after the selection of a welding wire with the correct composition, good joints were achieved (see figure 17).

Big problem remains the fact that up until now a joint with a good quality can only be achieved with a welding speed of "only" 2 m/min. At this speed, it's possible to achieve a good a to b ratio (see figure 18) which is the result of enough heat generated in the weld pool to melt away the oxide skins present between both sheets. When using a higher welding speed, not enough heat seams to be present to achieve the same high a to b ratio. This is also the case when the gap between both sheets becomes larger what surely can happen when welding large deep drawn shells on a production installation. Further research work is done to overcome these problems.

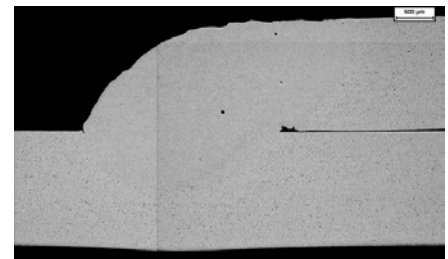


Fig. 17 Achieved weld seam quality with mono beam laser

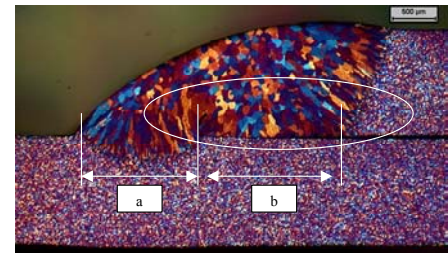


Fig. 18 a/b ratio

CORROSION BEHAVIOUR

Fuel tanks are submitted to following two main types of corrosion. First of all, fuel tanks are submitted to what one could call outside or atmospheric corrosion. Depending of the position of the fuel tank under the car, attack by this type of corrosion will be more or less severe. Despite of this fact, it's our goal to proof that even in the worst conditions aluminium without an additional coating can withstand this corrosion attack. It needs to be mentioned that the automobile manufacturer judged this type of corrosion as being the most critical one. After all, aluminium is much more sensitive to pit corrosion (see figure 19) than steel. Taking this into account and the fact that a fuel tank is a safety component, the possible growth of a pit through the complete wall thickness of a fuel tank must be excluded with 100 % certainty.

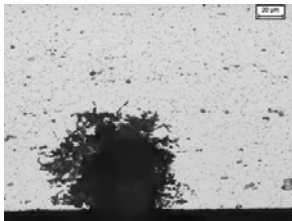


Fig. 19 Typical result of pit corrosion

A second type of corrosion generated by fuels could be called fuel or inside corrosion. Due to the fact that gasoline fuels contain most probably in the future a higher percentage of ethanol and due to the fact that diesel fuels contain most probably in the future a (higher) percentage of RME (Rapeseed Methyl Ester), these fuels become more and more aggressive. As a consequence, different current steel coatings will not be able anymore to withstand corrosion caused by these types of fuels.

Both fuel and outside corrosion tests could be executed according to national and international standards or even according to guidelines agreed upon by working groups as

for instance the SASFT [Ref. 7].

However, it became clear that almost all automobile manufacturers have their own test procedures. After the execution of fuel corrosion tests at the Welsh Technology Centre at the beginning of the project according to the so-called Inland Steel fuel test, it was decided to only execute further tests according to existing specifications of the automobile manufacturer or specifications selected and agreed upon with the automobile manufacturer.

OUTSIDE CORROSION

Samples of alloy type 5018 and 5182 with a bulge in one part of the flat sheet were, after being sensitised at an elevated temperature, covered with laboratory dirt containing some amounts of Cu, Fe and Cl. It's common knowledge that these elements are very aggressive towards aluminium. All samples were subjected to a salt spray test during 1 day and afterwards during 6 days put into a climate chamber with changing temperature and humidity. After rinsing the samples and putting on new laboratory dirt, this complete cycle was repeated 3 more times. It became very soon clear that alloy 5182 couldn't withstand this very severe corrosion conditions. Cracks occurred in the deformed (bulge) area as can be seen in figure 20.

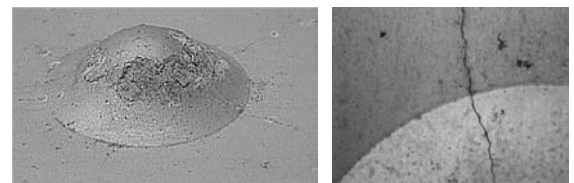


Fig. 20 Cracks present in alloy 5182 after outside corrosion test

By means of a very accurate and statistical reliable measuring technique, pit depths of all samples taken out of the test after 1, 2, 3 and 4 weeks were determined to evaluate the evolution of the pit depths. It became clear that, despite of the fact that new aggressive laboratory dirt was put on the samples after each cycle (1 week), pit depths don't grow anymore after 1 week (see figure 21).

In other words, alloy type 5018 without (additional) protective coating withstood this outside corrosion test without problems. To be by a manner of speaking 1000 % sure, this test will be repeated during 16 weeks. Furthermore, other aluminium and steel grades will be added to the test and some samples will be subjected to slightly different test parameters to gain more knowledge about the corrosion mechanisms.

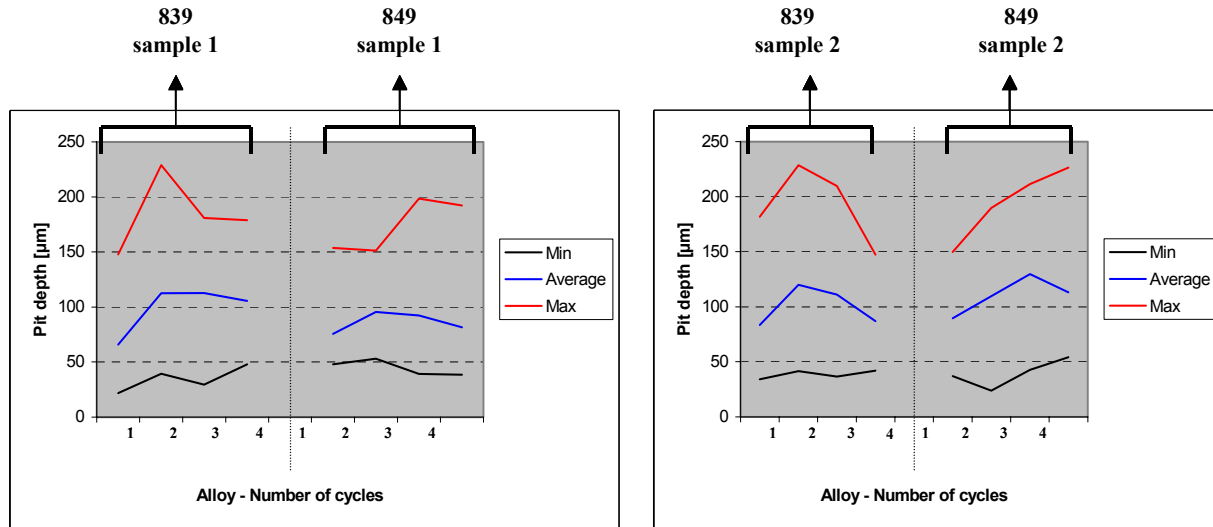


Fig. 21 Evolution of pit depth

FUEL CORROSION

As mentioned before, first fuel corrosion tests were executed according to the so-called Inland Steel Fuel test. This in house test that comes originally from Inland Steel was adapted and extensively used in the past by the Welsh Technology Centre to test amongst others tern plate produced by the Cookley plant of Corus. The tests executed on steel samples in the past demonstrated that an exposure over a 24-week period to fuels at a temperature of 60°C generates corrosion equivalent to 10 to 15 years real time exposure.

Samples of different aluminium alloys and temper (1050 O/H111, 5754 H22, type 5018 O/H111, 5083 O/H111 and 5182 O/H111) were, after being sensitised under various conditions as for instance 40 days ageing at 120°C, subjected to 4 different kinds of fuels, namely diesel 5% H₂O, 85% methanol + 15% unleaded petrol, unleaded petrol and 85% methanol containing 5% H₂O, 20ppm formic acid & 15% unleaded petrol.

Two 5 mm Erichsen domes (one to be subjected to the vapour phase and one to be immersed in the liquid phase) were pressed into each panel because it's common knowledge that deformed zones have a different corrosion behaviour. All panels were then placed in a sealed jar with only one half of the panels immersed in the selected fuel. All jars were subsequently placed in water baths and maintained at 60°C.

The fuels and seals in each jar were changed once a fortnight. At these moments, the condition of the part of the samples that was subjected to the vapour phase was evaluated and noted down. The same was done for the part of the samples that was subjected to the liquid phase.

Concluded could be that all aluminium alloys performed very well in all conditions. Figure 22 shows the surface aspect of the samples of alloy type 5018 after being submitted 24 weeks to the so-called Inland Steel fuel corrosion test.

The surface of the samples subjected to the unleaded petrol exhibited the most staining. However, no real corrosion attack (as for instance pit corrosion, etc...) could be observed. When samples exhibited staining, it occurred on both the immersed surface as the surface above the fuel line.

With respect to heat treatment, samples that were sensitised during forty days exhibited less staining as samples sensitised during 10 or 20 days. As a result of these "preliminary" tests / results, a good impression was gained of the most important influencing parameters and this allows us to focus on a more limited amount of alloys when executing the fuel corrosion tests according to the specifications agreed upon with the automobile manufacturer.

These tests take into account recent and future developments as for instance new (environment friendly) fuels and higher fuel temperatures caused by direct injection in spark ignition engines and direct injection/common rail (CDI) diesel systems [Ref. 8] but also longer durability requirements.

These fuel corrosion tests are, compared to the already executed tests, more aggressive due to the fact that

- the selected fuels contain more aggressive components,
- the tests will be executed at higher temperatures and during a longer period and
- a temperature cycle is included.

INTERGRANULAR CORROSION

Intergranular corrosion is often mentioned as a reason to exclude the use of aluminium for some application if the temperatures become too high [Ref. 5]. Concerning this topic, it's important to mention that this type of corrosion only occurs in case of aluminium alloys containing more than 3% Mg. Even more important to mention is the fact that Corus Aluminium N.V. produces already many years a 3,5% Mg containing alloy and recently developed a 4,3% Mg containing alloy with an intergranular corrosion behaviour as good as the so-called intergranular corrosion free alloy 5754 that contains only 3% Mg. As a consequence, intergranular corrosion is something to be kept in mind but is certainly no reason to exclude aluminium as a base material for the production of a fuel tank.

SUMMARY AND CONCLUSIONS

An overview is given of the most relevant parameters and technologies that favour the application of an aluminium fuel tank for passenger cars in the future.

A tremendous amount of research is already done and makes clear that aluminium has clear potentials and advantages to be used for the production of environment friendly (lightweight, zero permeability, recyclability, etc...) fuel tanks for passenger cars. Nevertheless, further research still needs to be done to optimise the found solutions and to upgrade these solutions to cost effective and reliable production methods.

ACKNOWLEDGEMENTS

The authors wish to thank all employees of DaimlerChrysler Stuttgart and Inalfa Hamont-Achel involved in the projects for the good cooperation and the permission to publish the achievements.

CONTACT

- One of both main authors is a researcher at the Aluminium Metallurgy group of Research, Development & Technology (www.corusgroup.com). The address is: Koos van Rijkom, CORUS GROUP, PO Box 10.000, 1970 CA IJmuiden, The Netherlands; e-mail: koos.van-rijkom@corusgroup.com; tel. +31 (0) 2514 94845; fax +31 (0) 2514 70264.
- The other main author is a Manager Product and Market Development of the Business Group Corus Aluminium Rolled Products, Duffel, Belgium (www.corusgroup-duffel.com). The address is: Axel Smeyers, Corus Aluminium N.V., A. Stocletlaan 87, 2570 Duffel, Belgium; e-mail: axel.smeyers@corusgroup.com; tel. +32 (0) 15 302648; fax +32 (0) 15 302789.
- Lou Janssen is responsible for Advanced Engineering at Inalfa Metal Products. The address is Lou Janssen, Inalfa Metal Products B.V., Nobelstraat 2, 3930 Hamont-Achel, Belgium; e-mail: lou.janssen@inalfa.be; tel. +32 (0) 11 440300; fax. +32 (0) 11 440350

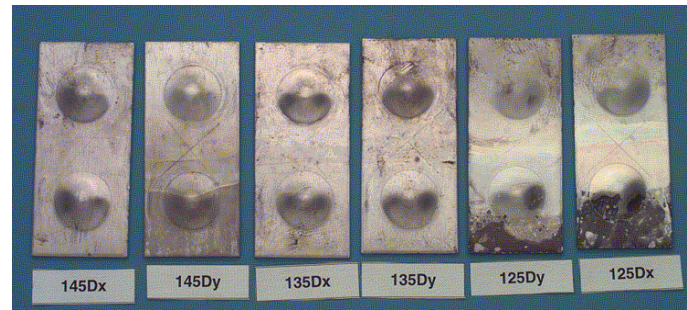


Fig. 22 Surface aspect of alloy type 5018 after the fuel corrosion test

REFERENCES

- [Ref. 1] <http://www.plasticstechnology.com/articles/200012fa1.html>
- [Ref.2] Neues Tankkonzept für LEV II und pZEV-Fahrzeuge
Albert Böcker, Michael Klöß - TI Group
Sonderausgabe von ATZ und MTZ – System Partners 2001
- [Ref.3] Fuel for thought
Ian Adcock
AUTOMOTIVE DESIGN November 2001
- [Ref. 4] Anwendung der Hydroblechumformung zur Herstellung eines PKW-Kraftstofftanks
Friebe, E.; Langhammer, T.; Kleiner, M.;Homborg, W.; Neubert, J.; Birkert, A.
Page 173 → 186
7. Sächsische Fachtagung Umformtechnik 24./25. Oktober 2000
Leichtbau durch Umformtechnik
- [Ref. 5] http://www.steel.org/autosteel/pdfs/ppt_2002_sasft_air_resources_board.pdf
- [Ref. 6] Steel Battles Plastic for Fuel Tank Application: Forming – Joining – Corrosion Resistance
Juergen Froeber, Hartwig Roesen and Ingo Wonneberger (Thyssen Krupp Stahl AG)
Wilhelm Warnecke (Dortmunder Oberflaechencentrum GmbH, A Company of ThyssenKrupp Steel)
Douglas W. Paul and Gregory Tarrance (Magni-Group)
- [Ref. 7] http://www.steel.org/autosteel/fuel_tanks/index.htm
- [Ref. 8] CARB's 'global warning' sets the challenge
EUROPEAN AUTOMOTIVE DESIGN February 2000
Page 30 → 35.

tank.tech²⁰⁰³

Dieser Vortrag wurde im Rahmen der Tagung **tank.tech 2003**,
20. – 21. November 2003 in Fürstenfeldbruck bei München,
gehalten.

This paper was presented at the conference **tank.tech 2003**,
November 20th and 21th, 2003, Fürstenfeldbruck, Munich, Germany

Die nächste Tagung dieser Tagungsreihe findet im November 2005
statt. Vortragseinreichungen sind ab Anfang 2005 willkommen.

Our next conference concerning the automobile fuel system will take
place November 2005. Experts are invited to submit abstracts with
the beginning of 2005.

Anmeldung und Auskünfte **Registration and Information**

TÜV Akademie GmbH
Tagungen und Kongresse
Westendstraße 199
D-80686 München / Munich, Germany

Ute Alius

Telefon +49 (0) 89 5791-1647
Telefax +49 (0) 89 5791-2833
E-mail: ute.alius@tuev-sued.de